

Extrasolar Terrestrial Planets: Can We Detect Them Already?

Michael Endl

*McDonald Observatory, The University of Texas at Austin, Austin, TX
78712, USA*

Martin Kürster

*Thüringer Landessternwarte Tautenburg, Sternwarte 5, 07778
Tautenburg, Germany*

Frédéric Rouesnel

*UFR DESS - Observatory of Paris-Meudon, F-92195 Meudon cedex,
France*

Sebastian Els

*Isaac Newton Group of Telescopes, Apartado de Correos 321, E-38700
Santa Cruz de La Palma, Spain*

Artie P. Hatzes

*Thüringer Landessternwarte Tautenburg, Sternwarte 5, 07778
Tautenburg, Germany*

William D. Cochran

*McDonald Observatory, The University of Texas at Austin, Austin, TX
78712, USA*

Abstract. With the example of Proxima Centauri we discuss the feasibility of detecting terrestrial planets (1 to a few M_{\oplus}) using the high precision radial velocity (RV) technique. If a very high RV precision for M stars is achieved even planets with these extremely low masses become detectable. For Proxima Cen (M5V), one of the prime targets of our M stars planet search program using the UVES spectrograph and iodine cell at the ESO VLT UT2, we obtain a long term RV precision of 2.5 m s^{-1} . Based on numerical simulations we determine that this level of precision would have already allowed us to detect planets with $m \sin i = 4 \text{ to } 6 M_{\oplus}$ inside the habitable zone of Proxima Cen.

1. Introduction

All extrasolar planets orbiting main-sequence stars known to date are giant planets ranging in mass from $m \sin i = 0.12 M_{\text{Jupiter}}$ to $17 M_{\text{Jup}}$ (with i the unknown angle between the orbital plane and the plane of the sky). It is virtually

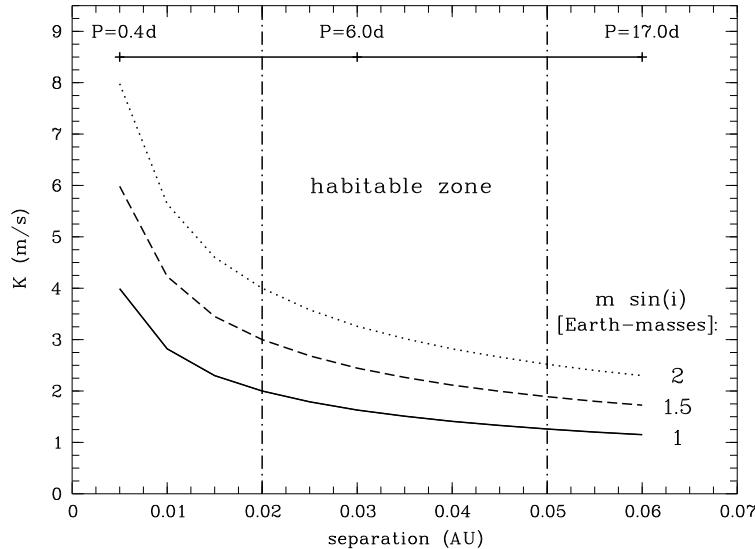


Figure 1. Simulation of radial velocity variations (RV semi-amplitude K) for a low-mass M dwarf ($0.1 M_{\odot}$) due to orbiting terrestrial planets plotted vs. orbital separation. The three curves display the K -amplitudes for planets with $m \sin i = 1 M_{\oplus}$ (solid), $1.5 M_{\oplus}$ (dashed) and $2 M_{\oplus}$ (dotted curve) residing in circular orbits. The vertical dashed lines show the borders of the habitable zone for this type of star after Kasting et al. (1993).

impossible to detect terrestrial planets (rocky objects of 1 to a few M_{\oplus}) around F, G and K-type stars using the high-precision RV technique, since Earth-mass planets induce only negligible reflex-motions on their host stars. This scenario changes in the faint and low-mass regime of the Hertzsprung-Russell diagram. In the case of M dwarf stars the low stellar primary mass leads to detectable RV amplitudes even for planets of a few M_{\oplus} and less in short-period orbits. Figure 1 shows the RV signatures of planets with $m \sin i = 1$ to $2.5 M_{\oplus}$ orbiting an M5V star with a mass of $0.1 M_{\odot}$. Due to its intrinsic faintness the habitable zone is located very close to the star (Kasting, Whitmire, & Reynolds 1993). This, too, favors the detection by the RV technique, since shorter periods also mean higher RV amplitudes. Although these nearby planets are probably tidally locked into synchronous rotation, a 3-D climate study by Joshi, Haberle, & Reynolds (1997) demonstrated that these planets are still likely to be habitable.

2. Searching for Terrestrial Planets Inside the Habitable Zone of Proxima Centauri

For the past two years we have used the ESO VLT and the UVES spectrograph to monitor a sample of 25 M dwarf stars in the southern hemisphere to search for planetary companions. Our RV results for Proxima Cen (M5V, $V = 11.05$), obtained with an enhanced version of our *Austral* radial velocity code (Endl,

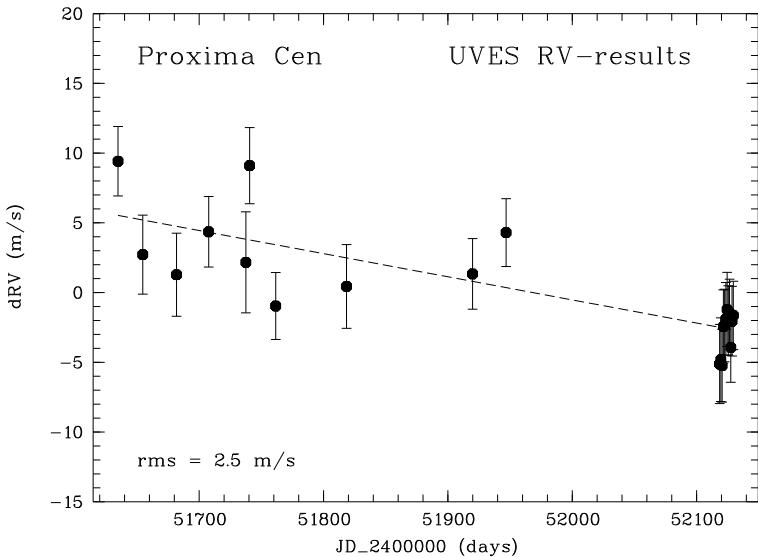


Figure 2. Differential radial velocity measurements of Proxima Cen obtained with the UVES spectrograph & iodine cell at the ESO VLT UT2 telescope. We find a linear acceleration of unknown origin (dashed line), the rms-scatter around this trend is 2.5 m s^{-1} .

Kürster, & Els 2000), are displayed in Figure 2. Over the time span of more than one year the star experiences a linear acceleration of unknown origin (and which is not present in the data of the other stars). The rms-scatter around this trend is 2.5 m s^{-1} .

2.1. Detection Sensitivity

We then take the 22 RV-measurements (after subtraction of the linear trend) and determine our planet detection threshold in the period range for orbits inside the habitable zone (2 to 16 days), using the technique from Endl et al. (2001). For the primary mass we adopt a value of $0.11 M_{\odot}$ after Henry et al. (1999). Figure 3 shows our momentary detection capability based on the RV data collected so far. With a confidence of $> 99\%$ we could have already detected *all* planets with $m \sin i$ values higher than 4 to 6 M_{\oplus} inside the habitable zone. With a chance probability of $\approx 50\%$ (i.e. only half of the test signals were recovered successfully with a confidence of $> 99\%$) we would have even found signals of planets down to $m \sin i \approx 2.5 M_{\oplus}$. These new constraints on planets inside the habitable zone of Proxima Cen supplement the existing limits for giant planets around this star by our ESO CES planet search program (Kürster et al. 1999) and the HST Fine Guidance Sensor astrometric results of Benedict et al. (1999).

3. Conclusions

Measuring RVs of M dwarfs with the appropriate high level of precision allows us to detect extremely low-mass planets in short period orbits. With the 22 RV

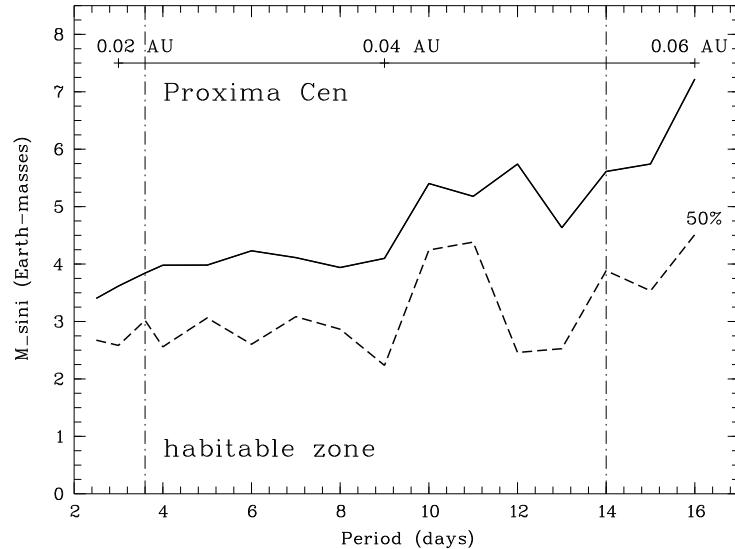


Figure 3. Detection threshold for low-mass planets orbiting inside the habitable zone of Proxima Cen. The solid thick line denotes the limit where we could have detected *all* planets with a confidence of $> 99\%$. Hence we can exclude the presence of planets with $m \sin i$ values on and above this line. The dashed line shows the limits where we had a 50% chance of detection.

measurements we obtained so far for Proxima Cen, we could have already detected *all* planets with $m \sin i = 4$ to $6 M_{\oplus}$ inside the habitable zone. So the answer to the title question is: *not yet*, but we get pretty close, and our sensitivity will further improve by extended monitoring due to the better sampling.

Acknowledgments. This work is supported by NASA Grant NAG5-9227 and by NSF Grant AST-9808980. We thank the ESO OPC and DDTc for generous allocation of observing time to our VLT M dwarf planet search program (Proposals 69.C-0722, 68.C-0415, 67.C-5700).

References

- Benedict, G. F. et al. (13 authors) 1999, AJ, 118, 1086
 Endl, M., Kürster, M., & Els S. 2000, A&A, 362, 585
 Endl, M., Kürster, M., Els, S., Hatzes, A. P., & Cochran, W. D. 2001, A&A, 374, 675
 Henry, T. J., Franz, O. G., Wasserman, L. H., Benedict, G. F., Shelus, P. J., Ianna, P. A., Kirkpatrick, J. D., & McCarthy, D. W. 1999, ApJ, 512, 864
 Joshi, M. M., Haberle, R. M., & Reynolds, R. T. 1997, Icarus, 129, 450
 Kasting, J. F., Whitmire, D. P., & Reynolds, R. T. 1993, Icarus, 101, 108
 Kürster, M., Hatzes, A. P., Cochran, W. D., Döbereiner, S., Dennerl, K., & Endl, M. 1999, A&A, 344, L5